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The Design of Seal Coats and Surface Treatments

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IT HAS BEEN apparent for a number of years that the methods commonly employed for estimating the quantity of asphalt and screenings and to control the placing of seal coats are not adequate to insure that satisfactory results will be consistently obtained.

Up to the present time, the accomplishment of a successful seal coat has depended upon skill and experience on the part of the engineer, the availability of suitable equipment and materials and above all upon good weather. However, there has never been an over supply of engineers experienced in this particular class of work and as a result of the rapid expansion in the California Highway Program, it is increasingly difficult to find experienced men for all of the numerous cases where seal coat construction is involved. The problem has been recognized for several years and the Materials and Research Department has been engaged in collecting information, making observations on current practice and as opportunity has permitted, has studied the problem involved in the designing and placing of seal coats on road surfaces.

Pertinent Discussion

In a recent paper entitled "The Use and Abuse of Seal Coats," Mr. C. V. Kiefer, (1), Member of the Engineering and Development Committee, Pacific Coast Division of The Asphalt Institute, presented a pertinent and timely discussion on the subject of seal coats. Mr. Kiefer has set forth in very readable form most of the factors which have an influence upon the success or failure of seal coats.

The purpose of this article is to describe the problem, to point out some of the factors involved and to outline the first steps of a definite engineering approach. While complete field data are lacking to support all of the conclusions and inferences drawn, nevertheless, it is believed that a start can be made and as more information becomes available, procedures can be adjusted or modified as found to be necessary. In any event, the field engineer or maintenance superintendent should be furnished with an orderly and logical procedure in order that the essential details of seal coat construction can be handled with greater assurance than is possible at the present time.

Some of Factors

Before attempting to present a design method, it will be desirable to discuss some of the factors affecting the quality and over-all performance of seal coats. As in the case of all bituminous road surfaces, seal coats are made up of two ingredients; namely a bituminous binder and stone chips or screenings. While the ingredients are relatively commonplace and simple, nevertheless, there are many variations in properties of both asphalt and stone and it is proposed to discuss some of these variations.

Before we can decide what is important and what is relatively unimportant, it is necessary to recognize the purpose for which a seal coat is being placed. The term "seal coat" implies that the original intent of this type of construction was to *seal* the road surface; that is, to prevent surface water from penetrating the pavement or base. However, all highway engineers will recognize that a surface treatment of asphalt and screenings may be applied to a road to accomplish *one or more* of several distinct purposes.

Distinct Purposes

These may be [illegible]

1. To *seal* the road [illegible] entrance of moisture
2. To develop a *non-skid* the existing road [illegible] ously smooth and [illegible]
3. To apply a fresh [illegible] which will *enliven* an or weathered surface prove wear resistance.
4. To *reinforce* and build quate pavement [illegible]
5. To provide a [illegible] fic guidance between tions and traffic lanes.
6. To improve *luminosity* night.

The above list indicates mate order of importance of purpose and it is [illegible] are commonly four or [illegible] reasons for placing such "seal coat" and therefore, asphalt binder, the [illegible] and size of screenings [illegible] selected intelligently if the [illegible] a clear conception of the each particular case.

California Method

A seal coat may consist more successive layers of binder and screenings but [illegible] ity of cases, at least in C[illegible] coat consists of one [illegible] asphalt on the existing [illegible] single application of scr[illegible] Standard Specifications for nia Division of Highways "Seal Coats": Class "A M[illegible] "A-Fine," Class "B-Single, Coarse," Class "C-Medium "C-Fine," all of which [illegible] application of liquid [illegible] with one layer of screenings the two layer seals such as "B-Double" and Class "C-"

chart, *Fig. 1*, has been in order to classify the factors involved when selecting the quantity of screenings. The shown in *Fig. 1* was made to indicate the factors which the quality of screenings, should be taken into ac- deciding upon the size and variables that will influence the required, particularly on a basis. These three primary quality, size and quantity were because it is evident that each be considered by the engineer an adequate set of specifi- and must also be recognized by in charge of construction to secure a satisfactory job.

Analysis Chart Indicating the Relationship or Influence of All Factors That May Affect the Choice and Performance of Screenings

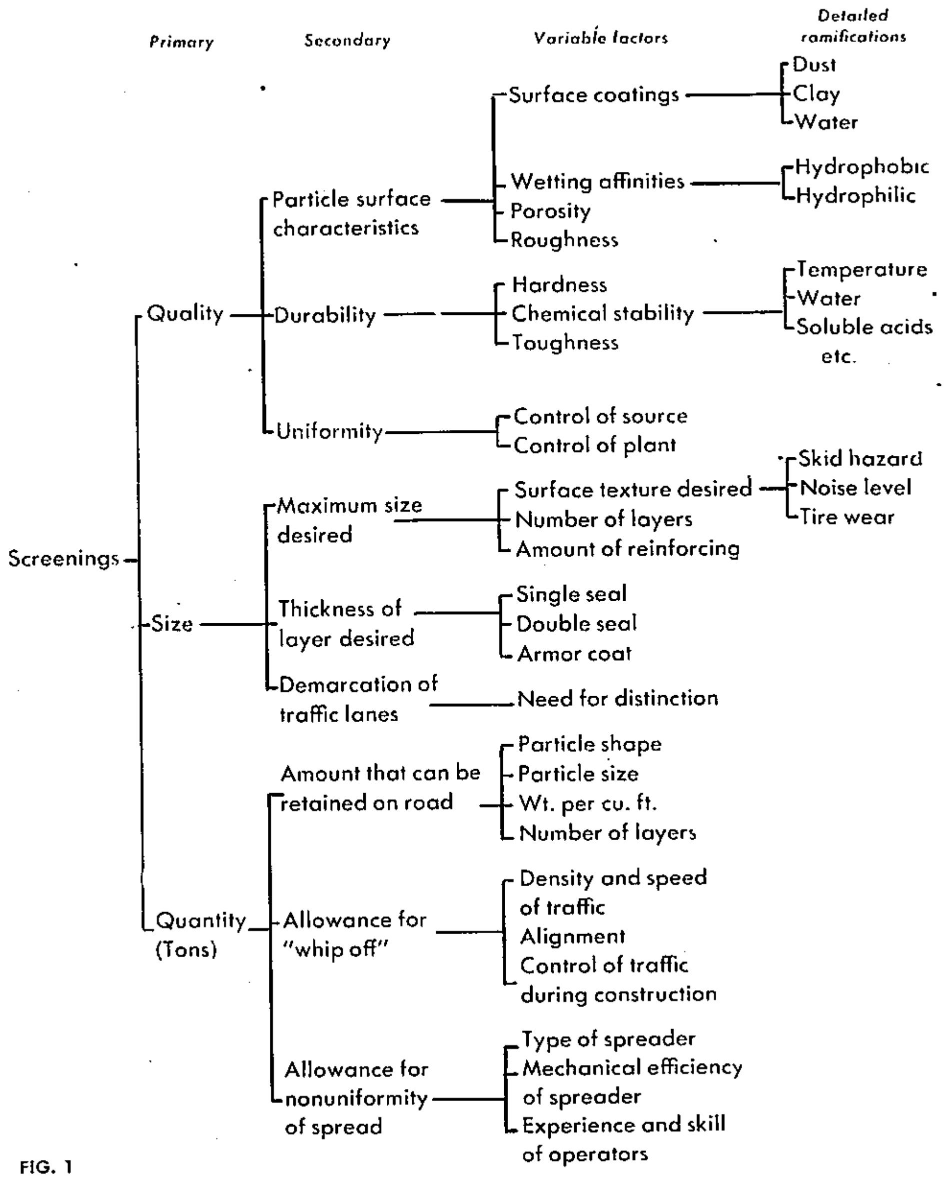


FIG. 1

Items on Figure 1

up the items on *Fig. 1* in first consideration must be given question: What do we mean we stipulate that the screenings of good quality? Common ex- indicates that many types of are durable, properly graded and with the proper surface will be satisfactory for of screenings, and it seem to be important whether are in the form of rock, screened gravel or gravel. Good results have been using any of these three types However, it is evident types of stone are not neces- used in equal amounts and also of the seal coat surface will vary somewhat depending the type of aggregate.

important that the screenings ability to retain a film of as- in the presence of water. In other the asphalt must wet the stone strip off when subjected to rain water. Mineral aggregates which asphalt can be stripped by of water are commonly "hydrophilic," meaning that the has an "affinity" for water. particles that hold asphalt tena- even when subjected to water are called "hydrophobic," mean- they avoid water. The question of adhesion affinities is ordinarily indicated by film stripping tests performed in the laboratory. Certain commercial additives or anti-stripping agents are being sold or proposed for use with the intent of improving the adhesion and thus permit the use of aggregates that otherwise would strip and be unsuitable. So far, these additives have not proved to be universally successful. A number of proprietary compounds are available, but in California practice a selection is made only after laboratory tests have indicated that a certain additive will improve the particular aggregate in question.

Porosity of Stone Particles

The porosity of the stone particles will have an effect upon the amount of oil or asphalt that will be taken up and the surface roughness may also have an influence. However, the question of surface coatings is probably the most serious and the surface films of dust, clay or moisture on the screenings have been responsible for a great many failures in seal coat construction. Like many other factors, these matters are relative, and damp aggregate may cause no trouble when the work is completed and properly cured or conditioned during warm weather. However, the same amount of moisture in the stone may result in failure when the work is carried on during cold weather or when the humidity is high. The weather condition during the construction period undoubtedly represents the most important single factor contributing to the success or failure of this type of construction.

The question of durability is primarily a problem for laboratory determination and need not be discussed in detail.

Size of Screenings

Uniformity is achieved by the control of plant operations and by efficient operation of the screening facilities.

The second principal factor shown in *Fig. 1* relates to the selection of the size of screenings. In selecting the size, the planning engineer must consider such questions as smoothness of the surface desired, whether or not consideration is given to the irritating noise or rumble in cars and the question of tire wear as well as that of providing an enduring or permanently non-skid surface. In order to make an intelligent selection of screening size, the engineer must give consideration to the primary reasons for placing the particular seal coat, referring to the six distinct purposes listed above in the introduction. It is evident that the selection of stone size will depend to a large degree on the reasons for placing the "seal coat."

At the present time, the choice of screenings for a single course construction on the state highway system generally involves consideration of only two sizes; namely, the *Medium* screenings having a nominal maximum size of ⅜″ and the *Medium Fine* in which 90 to 100 percent will pass a 5/16″ screen. Finer screenings have proved troublesome to spread and it is difficult to prevent "padding," or a wavy surface. Coarse screenings of ½″ maximum have been found to develop a noisy uncomfortable surface texture and they are undoubtedly responsible for increased tire wear.

Quality of Screenings

The third primary factor is the question of quantity. In the past, inaccuracy in estimating the quantities have not usually been responsible for failures. The principal errors have resulted in providing an excessive amount of screenings, which means waste and needless expense. Work in the laboratory of the Division of Highways has followed the lines originally laid down by Hanson in New Zealand, (2), who established the fact that regardless of the amount of screenings placed over a given application of oil, the final layer that adheres would be only one stone in thickness. A series of investigations carried out in California have tended to verify the findings of Hanson. It has been found, for example, that a maximum of 18 pounds of screenings per square yard represented an excellent coverage on the road using ⅜″ x No. 6 screenings. Experiments conducted in the laboratory indicated that for this size of screenings, 18 pounds per square yard represented a layer one stone thick.

Hanson's Conclusions

Hanson also concluded that for conditions in New Zealand it was necessary to make an allowance of about 10 percent extra material because methods of spreading were not 100 percent perfect and there is a certain amount of loss or "whip off" that occurs when the new surface is subjected to traffic. Under average conditions prevailing during construction in California, it is probable that an estimate of 20 percent allowance is justifiable. The proper allowance for "whip off" should be based upon the type of spreading equipment and perhaps upon the speed and volume of traffic.

Studies conducted by one of the authors, W. R. Lovering (formerly of headquarters laboratory and now Materials Engineer in District I stationed at Eureka) established a relationship between the effective maximum size of screenings and the volume of the same screenings which would produce a layer one stone thick. Hanson established a correlation between the average least diameter of the stone and the quantity of screenings required for coverage. This average least diameter was determined by caliper measurement which is hardly feasible with the screening sizes commonly used in California and an attempt was made to determine a more practical correlation.

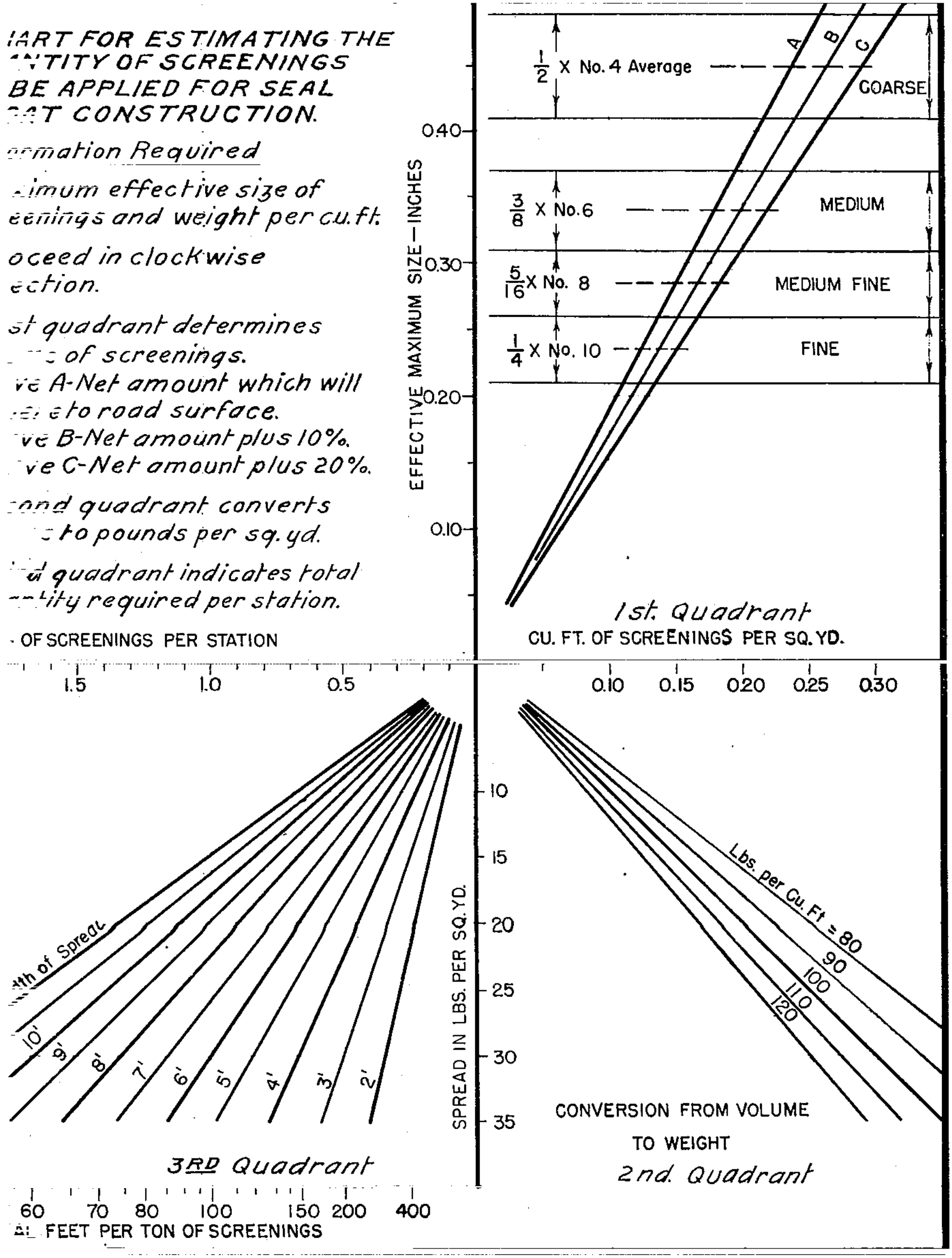
"Effective Maximum

A relationship was
tween the "effective
and the loose volume
screenings which
layer one stone thick as
sized screenings
ciable overrun in the
used. The effective
determined as the
in inches which would
of the screenings to pass
openings. Better
tained between the "
and the loose volume
screenings required to
one stone thick. The
may be defined as the
of the mean size of the
cent, the middle 60
smallest 20 percent of the
determined from a plot
curve. Screenings f
sources gave somewhat
however, indicating that
had not been considered.
most important of the
evaluated are the
faces of the rock and the
rock particles.

Quantity of

It is felt however, that
effective maximum size
ciently accurate results
present limitations of
methods and equipment,
other factors are kept in
basis of the foregoing, a
has been prepared as an
ing the quantity of any
required. This chart
justment for the size of
an allowance for either 10
"whip off." A correction f
variations in weight per
a final conversion to the
required per station
widths of spread is
possible to compute the
lineal feet which would
one ton of screenings for
widths of spread. The
the chart indicate the

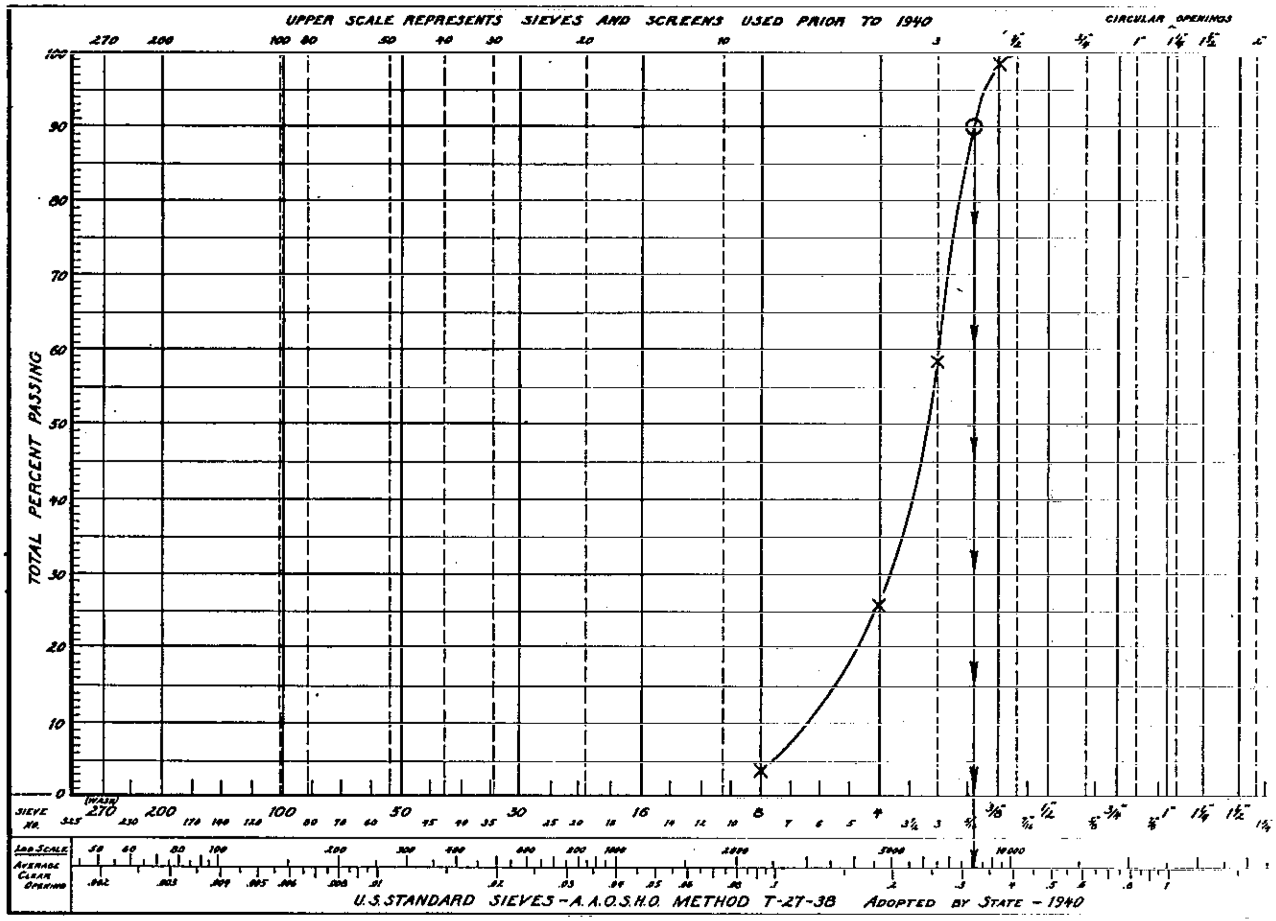
In order to use the
minations must be made
of information must be
a sieve analysis of the
be obtained and plotted
semi-log grading chart.



IART FOR ESTIMATING THE
…NTITY OF SCREENINGS
BE APPLIED FOR SEAL
…AT CONSTRUCTION.
…rmation Required
…imum effective size of
…eenings and weight per cu.ft.
…oceed in clockwise
…ection.
…st quadrant determines
… of screenings.
…ve A-Net amount which will
… to road surface.
…ve B-Net amount plus 10%.
…ve C-Net amount plus 20%.
…ond quadrant converts
… to pounds per sq. yd.
…d quadrant indicates total
…tity required per station.
EFFECTIVE MAXIMUM SIZE—INCHES
0.40
0.30
0.20
0.10
A
B
C
1/2 X No. 4 Average
COARSE
3/8 X No. 6
MEDIUM
5/16 X No. 8
MEDIUM FINE
1/4 X No. 10
FINE
1st Quadrant
CU. FT. OF SCREENINGS PER SQ. YD.
0.10
0.15
0.20
0.25
0.30
… OF SCREENINGS PER STATION
1.5
1.0
0.5
…th of Spread
10'
9'
8'
7'
6'
5'
4'
3'
2'
3RD Quadrant
60
70
80
100
150
200
400
…AL FEET PER TON OF SCREENINGS
SPREAD IN LBS. PER SQ. YD.
10
15
20
25
30
35
Lbs. per Cu. Ft. = 80
90
100
110
120
CONVERSION FROM VOLUME
TO WEIGHT
2nd Quadrant

Fig. 2

SEMI-LOG CHART FOR GRADING CURVES *Fig. 3*



curve, the effective maximum size in inches is determined by noting the size in inches on the bottom scale that corresponds to the point where the plotted graph crosses the line representing 90 percent passing. *Fig. 3.*

The grading chart, *Fig. 3,* gives an illustration showing a typical curve for a sample of medium screenings of nominal size ⅜″ x No. 6. In this case the curve crosses the 90 percent line at a point equivalent to a hypothetical screen having 0.32″ openings. This represents the effective maximum size of the screenings. Chart, *Fig. 2,* lists the standard specification screenings indicating the range of effective maximum size. The second item of information required is the loose weight per cubic foot of the particular screenings in question. Having the effective maximum size and the weight per cubic foot, the number of pounds of screenings required to cover one square yard can be determined from the chart.

SELECTION AND APPLICATION OF BITUMINOUS BINDER

Any bituminous material, whether asphalt or tar, that is suitable for sticking rock particles to the road surface must have certain properties. For seal coat construction, a bitumen should have good adhesion to the existing road surface and to the screenings. It should develop sufficient cohesive strength to hold the screenings in place and should develop this strength rapidly in order to prevent loss of screenings under traffic. The bituminous binder should be able to resist deterioration under conditions of outdoor exposure and not become hard or brittle for a substantial period of time. In addition, the bitumen should have the proper fluidity or consistency to permit ready and accurate application. As the conditions vary between projects, it is evident that no one grade of liquid asphalt will satisfy all of the requirements for every project considering the wide variety of conditions of the existing road of screenings, equipment climatic conditions ... countered in California.

Complex ...

While the selection ... grade and type of asphalt ... plex problem, it is often ... plicated by the ... dislikes of engineers. ... have a philosophical ... a poor job and it is only ... a certain project turns ... engineer understandably ... view of everything ... unlovely result, and it ... that the particular type ... phalt involved is blamed ... and condemned for all ...

In order for a ... hold screenings on the ... must adhere to the ... velop at least a ... cohesive strength. In the asphalts, this cohesion is and to some extent by The rate of evaporation is by the temperature of the amount and type of volatile temperature of the air, air movement and by the of exposed surface.

Temperature Factor

case of seal coats, the tempera- asphalt is determined by the of the pavement to which is applied. The pavement will, of course, depend upon the recent air tempera- will be definitely influenced to absorb heat directly as radiation from the sun. Thus, true that liquid asphalt in the summer months when are long and temperatures are reach the desired consistency period of time. During months, with shorter days and temperatures this interval can greatly extended depending weather conditions. However, it that hot weather may cause screenings because the asphalt For example, ROMC Cut- been observed to give good late summer or early fall but satisfactory in hot weather was too fluid because of temperature and still did not rapidly enough to hold the

Weather Condition Factor

Fig. 4, has been prepared to factors that bear upon the of the grade and type of bi- binder and includes the vari- should influence an esti- the quantity required. The that the prevailing condition is one factor having upon the choice of asphalt. it could be expected that curing cutback, RC-5, will set in consistency at a faster RORC-5. this latter product contains solvent, the base asphalt con- percentage of oily con- Thus, it might appear that the be preferable in cold work. However, the question intervenes as a base stock -5 is 85-100 penetration asphalt and ordinarily could be expected to reach the brittle point due to weathering in a shorter period of time. The best solution, of course, is to avoid placing seal coats or any other bituminous construction under adverse weather conditions. It has been suggested that a substitute treatment might be employed in the form of a light application of open-graded plant mix placed upon a heavy tack-coat in lieu of the orthodox seal coat when weather conditions are liable to be unfavorable.

Traffic Density Factor

Aside from durability reasons, the density of traffic to be carried is a factor. With increase in traffic and average vehicle speed, the problem of closing a road to traffic becomes more difficult. While it is essential that traffic be kept off the road until the asphalt reaches a consistency which will hold the stone chips in place, the setting time required will vary depending upon the type and grade of asphalt as well as the prevailing weather. This indicates the importance of using a rapid setting binder when construction must be carried on in the late fall.

The lower portion of the chart, *Fig. 4*, lists factors which have an influence upon the quantities of bituminous binder. These factors are the character of the screenings, the condition of the existing road surface, also the degree and kind of compaction to which the screenings will be subjected.

Under the heading "Character of Screenings" is included such things as particle gradation, particle shape, particle roughness and porosity. The gradation or sieve analysis of the screenings is an index to the amount of voids which must ultimately be filled with asphalt. The particle shape, that is, whether the stone chips are relatively cubical or flat will also have an influence on the void space. Particle roughness and porosity will take up additional oil compared to normal screenings. Hanson pointed out that the amount of asphalt should range from 0.5 to 0.7 of the voids in the aggregate as placed and compacted on the road.

Particle Shape Factor

While sieve analyses are easily made and the surface capacity of the stone due to roughness and porosity can be evaluated by noting the amount of light lubricating oil that will be retained by the screenings when drained under standard conditions (4), the factor of particle shape or cubicity is less easy to evaluate. Hanson (2), recognized the effect of cubicity in the screenings and proposed that the least dimension of individual rocks of a representative sample should be measured. Hanson averaged the least dimension of a number of particles and estimated the amount of oil from this average value. However, Hanson was dealing largely with coarse stone ranging from ½-inch to ¾-inch in size and as stated above his method of measuring individual particles by means of calipers does not seem practicable for the smaller sized screenings now used in California.

A method having better possibilities was developed by Egberto F. Tagle (3) of Argentina. This procedure involved the use of slotted screens which provide a particle size analysis based upon least dimension rather than upon maximum size of the rock particle. By comparing this type of grading analysis to the grading produced by standard screens, Tagle derived a factor which he designated the "cubicity factor" and the quantity of oil recommended in Argentine practice was based upon this factor. They also consider that "cubical" shaped particles are most satisfactory.

Oil

In the design chart, *Fig. 5*, the quantity of oil to be applied is based upon the *maximum effective size* of the screenings derived from a standard sieve analysis rather than upon the cubicity or average least dimension. This method has been selected because it is at the present moment more applicable than are the procedures proposed by either Tagle or Hanson.

Correction for Porosity

The particle roughness and porosity can be determined by methods described in connection with the Centrifuge Kerosene Equivalent Test for establishing the surface factor K_c (4). The design chart, *Fig. 5*, carries an allowance for porosity of the stone in the third quadrant of the chart. (The factor K_c may be determined by measuring the amount of No. 10 lubricating oil retained by the screenings after they have been soaked in the oil and then drained under controlled temperature conditions.)

In considering a correction for porosity using the factor K_c, it must be pointed out that this correction represents the amount of oil that will ultimately be absorbed by the screenings and the rate of absorption will depend upon the consistency of the bituminous binder which, in turn, is a function of temperature. As the temperature of an asphalt film in any sort of road mix or penetration treatment is controlled entirely by the temperature of the road surface or the aggregate, it is evident that absorption may take place very slowly when the road surface is cold and as a result the asphalt applied to compensate for absorbent aggregates may appear to be excessive and bleeding may develop before the excess is absorbed. However, at some future time when the pavement temperature rises, the oil may be absorbed and if a sufficient quantity is not applied in the first instance the absorption may leave an insufficient amount to hold the screenings in place. Therefore, it appears that screenings composed of highly porous stone will be particularly unsuited for cold weather work. It is not the intent to suggest that the ultimate amount of asphalt be applied during cold weather for a seal using porous aggregate. The inevitable result would be that sand would be applied to take up the apparent excess and the surface would dry out sooner or later. It is probable that the best solution is to avoid porous aggregates when possible.

Chart, *Fig. 5*, includes a correction for the porosity of the old road surface and it should again be emphasized that weather conditions and the presence of moisture may have a definite influence on the rate at which the oil is absorbed.

Summary of Factors

To summarize, it is recognized that the quantity of screenings required to cover the road surface will vary depending upon the size of the screenings and hence, the dimensions of the stone. Thus, a greater weight in volume of screenings will be required to develop a coverage of ½-inch screenings than will be required if ¼-inch size is used. As the screenings vary in weight per cubic foot, a correction must be made

Analysis Chart Indicating the Relationship or Influence of All Factors That ... the Choice and Performance of Bituminous Binder

(Assuming That the Bituminous Binder Is of Suitable Quality)

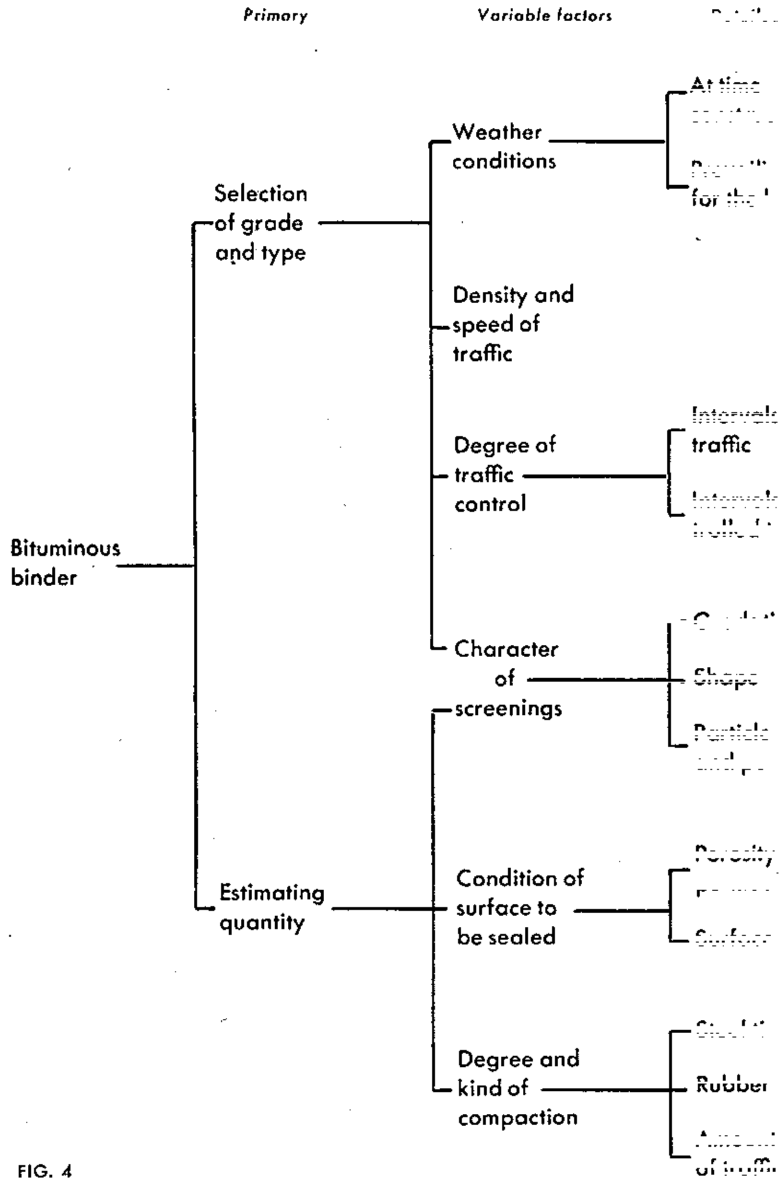


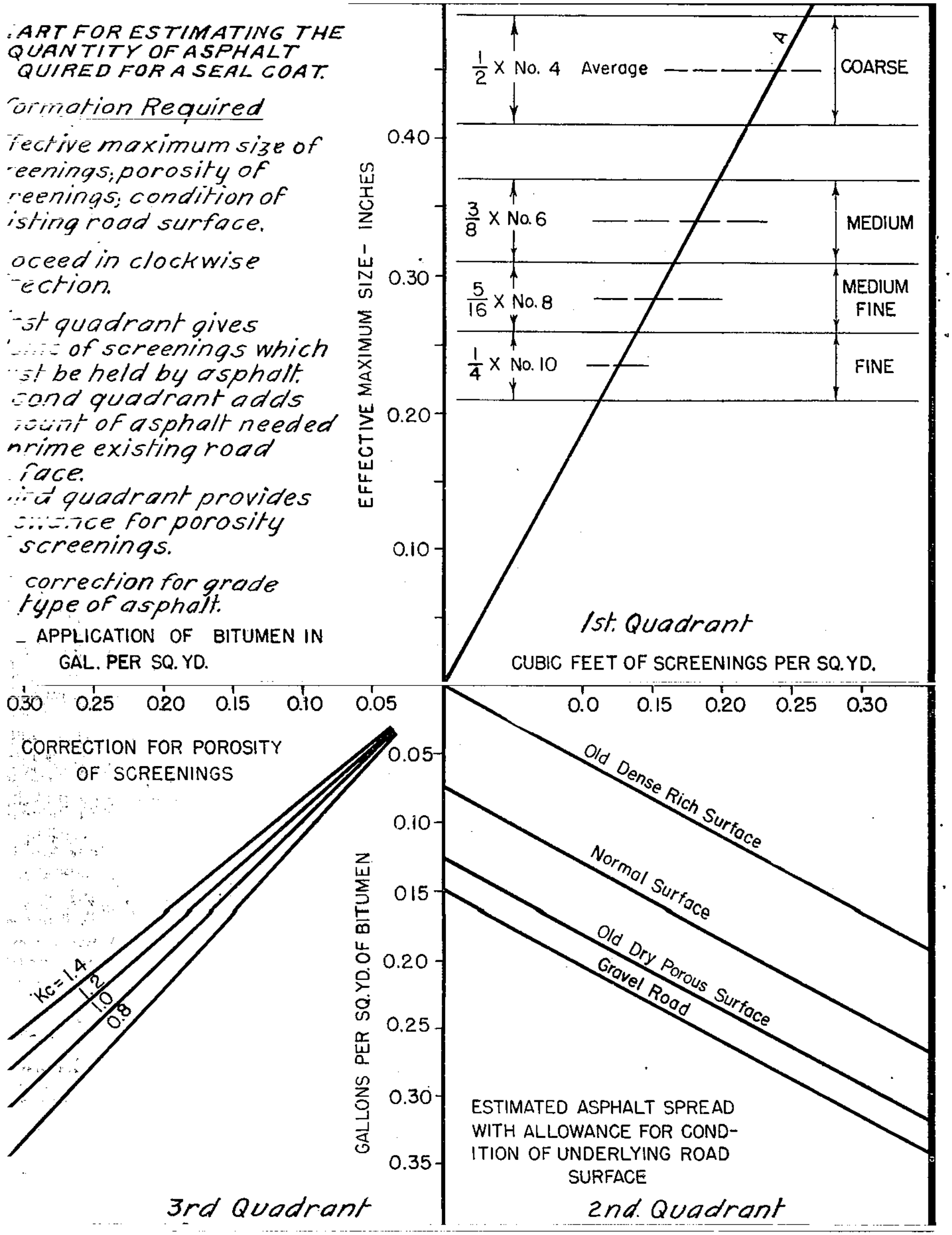
FIG. 4

in the number of pounds per square yard or the number of tons per station to compensate for variations in the volume-weight relationship. The amount of asphalt required is a function of the voids existing in the layer of screenings applied to the road. The total application of asphalt is also influenced by the amount necessary to prime the existing road surface which means that the existing surface must be evaluated in order to determine how much of the application will be taken up as a prime. Finally, there will be

some variability when ... are definitely porous. The ... uation of these variables ... accurate estimate of the ... cation and the total ... required.

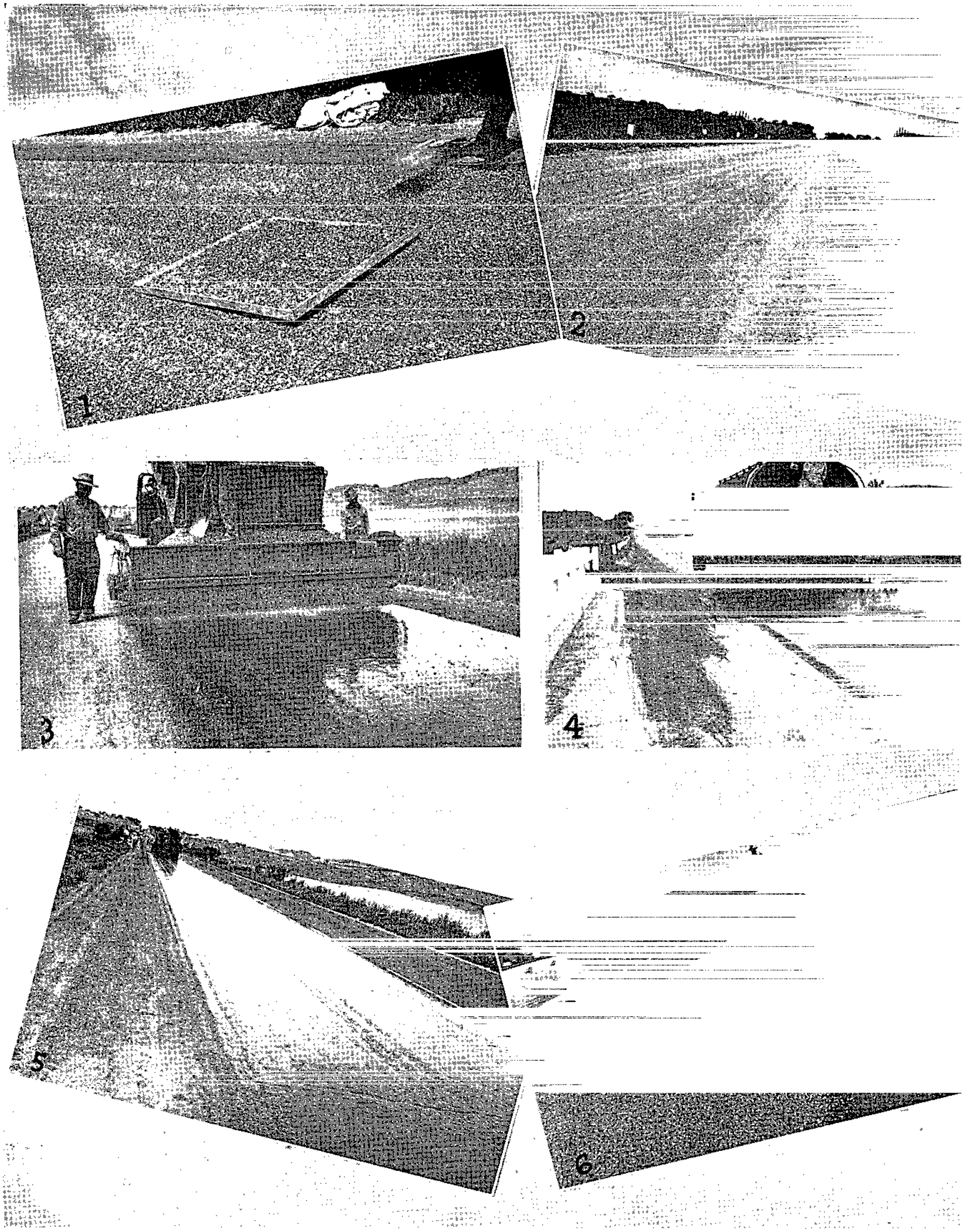
Selection of ...

A casual survey of C... tice indicates that the ... phalts for seal coat ... around the SC-6 grade. SC ... of 200-300 penetration ... be very satisfactory. How...



ART FOR ESTIMATING THE
QUANTITY OF ASPHALT
QUIRED FOR A SEAL COAT.
ormation Required
fective maximum size of
eenings; porosity of
reenings; condition of
isting road surface.
oceed in clockwise
ection.
st quadrant gives
of screenings which
st be held by asphalt.
cond quadrant adds
ount of asphalt needed
prime existing road
face.
rd quadrant provides
ance for porosity
screenings.
correction for grade
type of asphalt.
APPLICATION OF BITUMEN IN
GAL. PER SQ. YD.
EFFECTIVE MAXIMUM SIZE - INCHES
0.40
0.30
0.20
0.10
1/2 X No. 4 Average
3/8 X No. 6
5/16 X No. 8
1/4 X No. 10
COARSE
MEDIUM
MEDIUM FINE
FINE
A
1st Quadrant
CUBIC FEET OF SCREENINGS PER SQ. YD.
0.30 0.25 0.20 0.15 0.10 0.05
0.0 0.15 0.20 0.25 0.30
CORRECTION FOR POROSITY OF SCREENINGS
Kc=1.4
1.2
1.0
0.8
GALLONS PER SQ. YD. OF BITUMEN
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Old Dense Rich Surface
Normal Surface
Old Dry Porous Surface
Gravel Road
ESTIMATED ASPHALT SPREAD WITH ALLOWANCE FOR CONDITION OF UNDERLYING ROAD SURFACE
3rd Quadrant
2nd Quadrant

Fig. 5



1—A tray representing one square yard placed on pavement to determine uniformity of distribution of screening spreader. 2—A newly 3—Screenings being applied to the surface with a mechanical spreader. 4—Distributor truck starting spread of asphalt. 5—Freshly applied following passage of distributor. 6—Screenings being rolled with a tandem roller asphalt distributor could not in order to apply the desired. The quantity of SC-6 be cut down to the desired causing skipping or streak- sprays. For this reason, the has often been diluted with and many projects have been with MC-3, 4 or 5, or with 3, 4 or 5, all of which repre- of soft asphalt and a kero- of cutter stock.

to avoid loss of screenings slow setting of kerosene cut- types have been preferred in However, the standard of rapid curing cutbacks are from base stock of 85- asphalt and in order to advantage of a softer base as- special grade of cutback is the California Standard Speci- and designated as RORC-5 of 200-300 penetration as- cutback with a small amount of solvent.

Emulsified Asphalt

method for reducing the and thus permitting light ap- to be made with a high de- uniformity is the use of emulsi- A great deal of satisfactory seal coat construction has been accomplished by the use of emulsions. From evidence now available, it does not appear that it is necessary to make any distinction in the quantities of asphalt used whether soft paving grades, cutback or emulsion.

Ordinary emulsions of the penetration or mixing type have a viscosity ranging from 20 to 100 seconds. Emulsions of this type have a tendency to run off the road on steep grades, especially on superelevated curves. In order to avoid this difficulty, special emulsions have been developed giving a viscosity range from 200 to 400 seconds or even greater. These emulsions have noticeably less tendency to run off the road. However, the high viscosity of emulsions can be achieved in different ways and in certain cases an increase in viscosity has been accompanied by a slower setting which resulted in the loss of screenings.

It is hoped that the foregoing outline will help to clarify the problem and that the charts and method of calculation will serve to remove some of the uncertainties involved in current practice.

The procedure proposed is not considered to be complete or final and may be subject to correction or modification when more data are available.

It is desired to acknowledge the helpful comments and suggestions of Mr. T. H. Dennis, Maintenance Engineer; Mr. Nelson Bangert and Mr. Clarence Woodin of Headquarters Maintenance Department, Mr. G. A. Tilton, Jr., Assistant Construction Engineer; Mr. C. E. Bovey, Assistant District Engineer at Stockton, and Mr. C. V. Kiefer, member of the E & D Committee, Pacific Coast Division of the Asphalt Institute.

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